Section VI: Displacement Damage and Special Issues for Optoelectronics

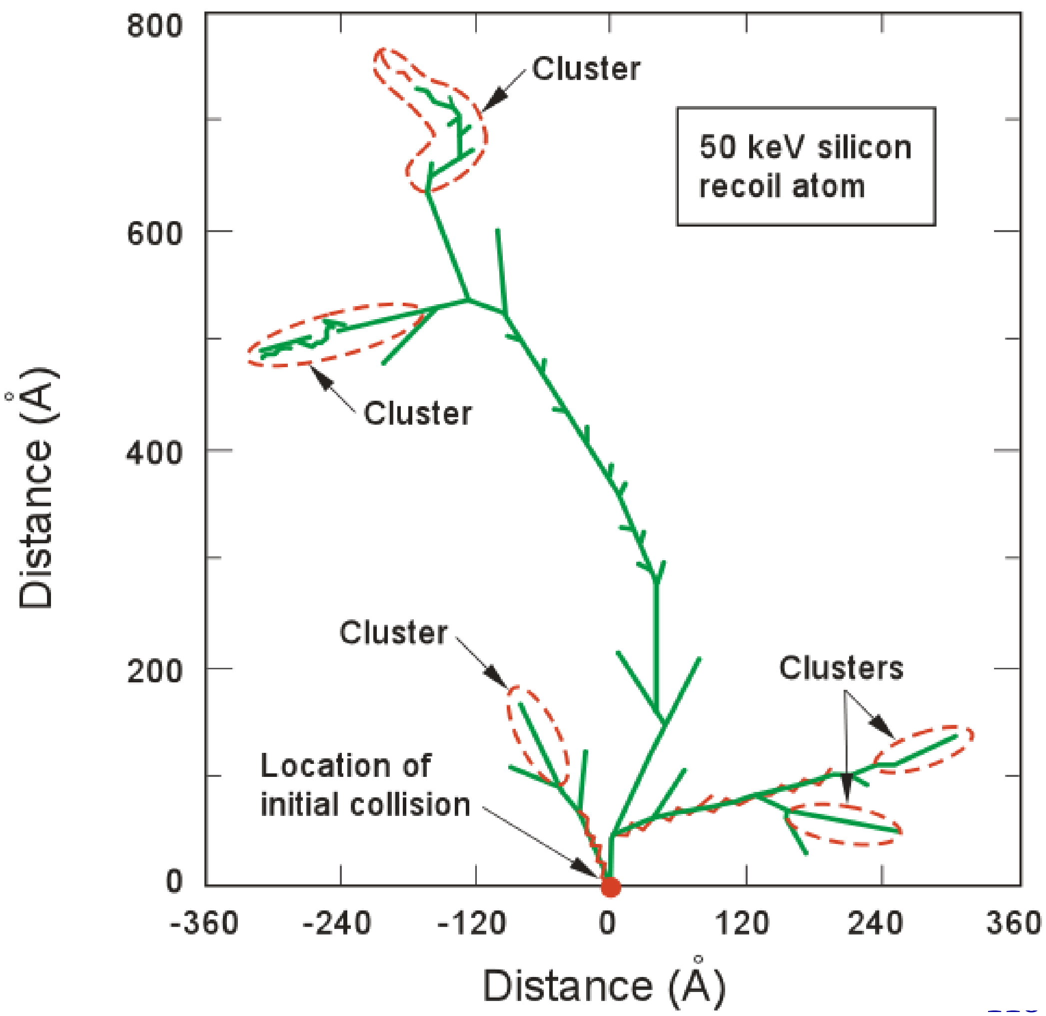
Allan H. Johnston
Electronic Parts Engineering Office
Section 514

Displacement Damage for High Energy Transfer

<u>Displacement Cascade</u>

Several damage clusters are produced by the collision

Damage is caused by movement of lattice atom after primary collision



Displacement Damage

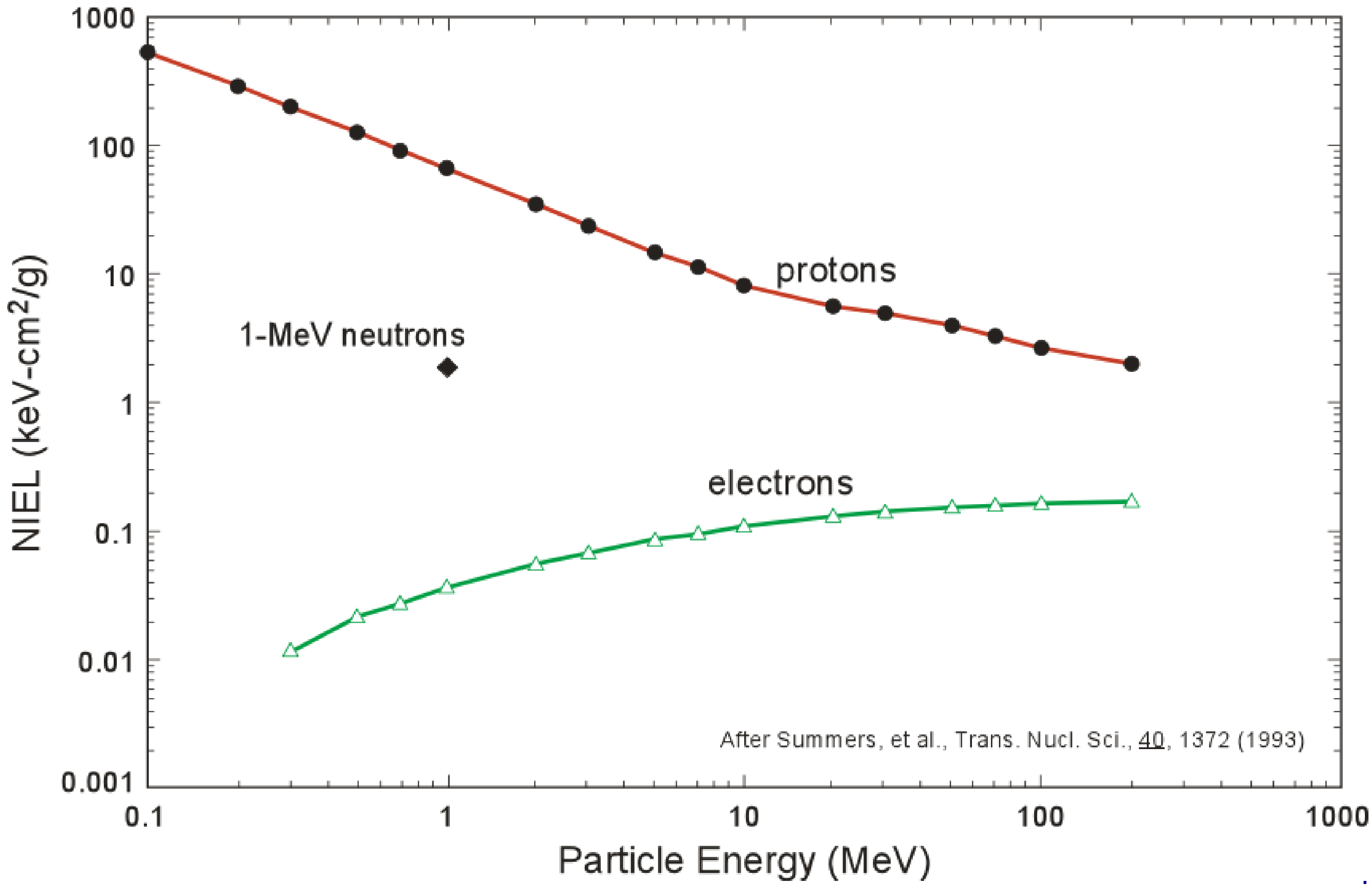
Effects of Displacement Damage in Semiconductors

- Minority carrier lifetime is degraded
  - Reduces gain of bipolar transistors
  - Also affects optical detectors and some types of light-emitting diodes
  - Effects become important for proton fluences above 1×10^{10} p/cm^2
- Mobility and carrier concentration are also affected

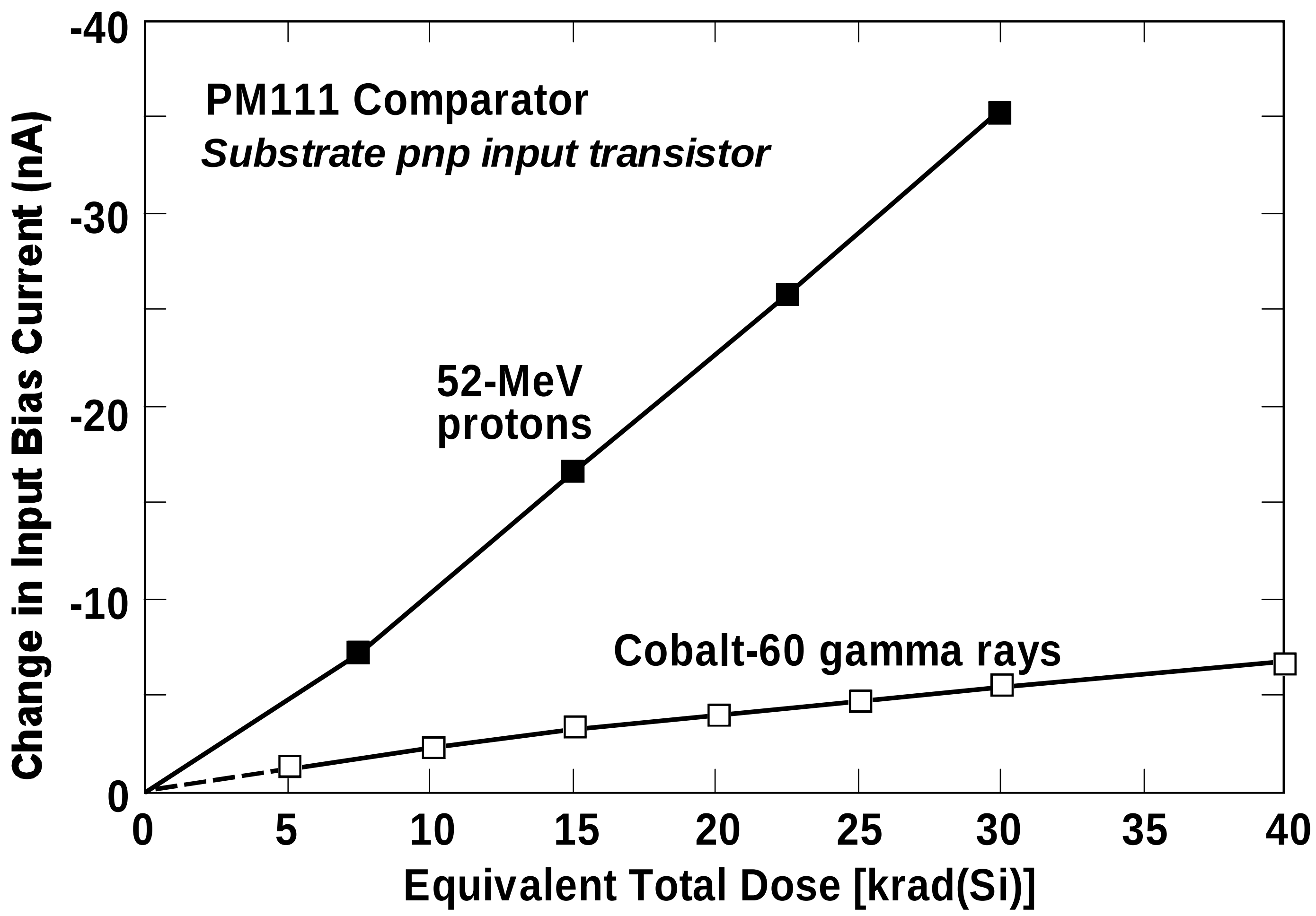
Particles Producing Displacement Damage

- Protons (all energies)
- Electrons with energies above 150 keV
- Neutrons (from on-board power sources)

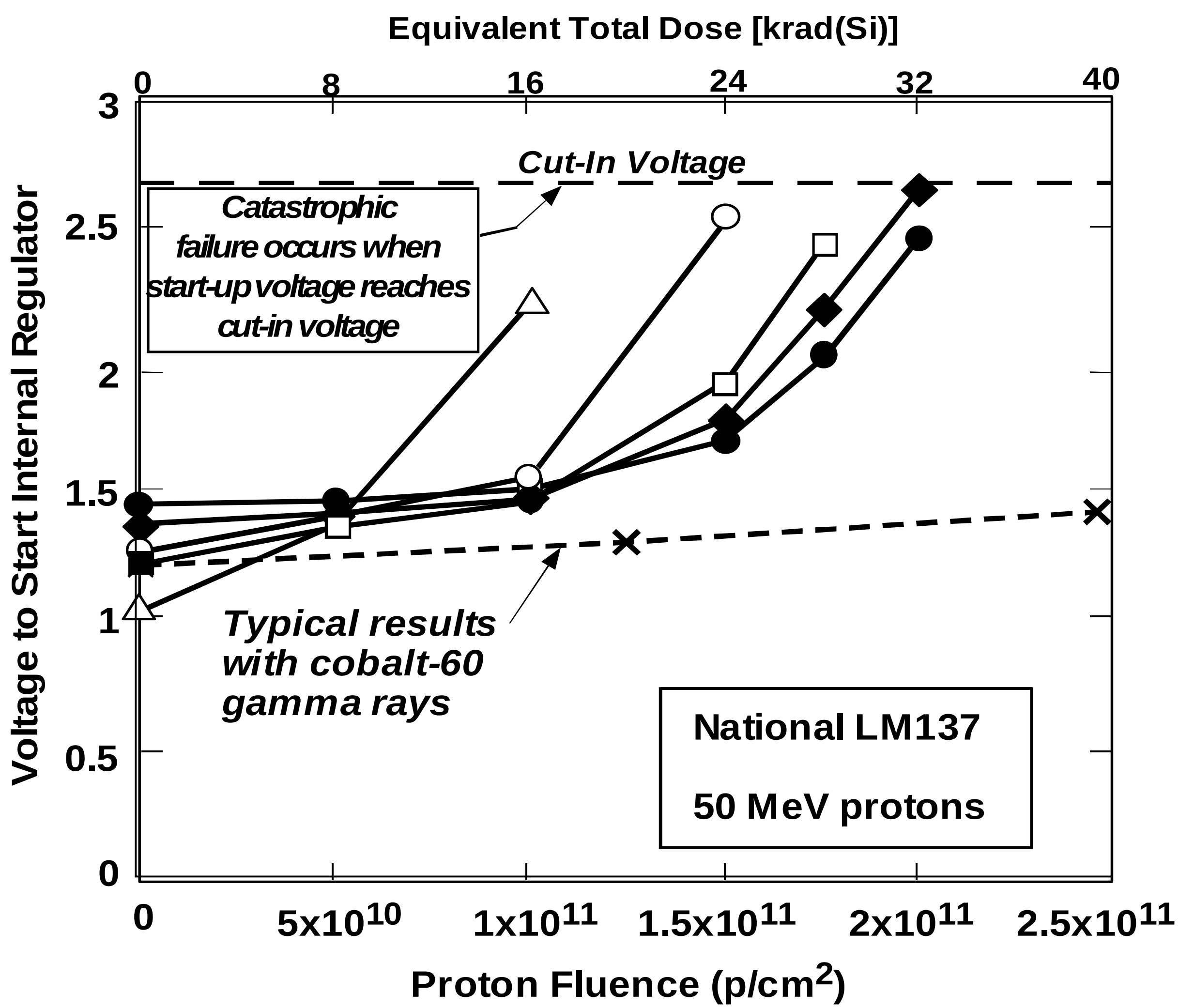
Energy Dependence of Displacement Damage in Silicon



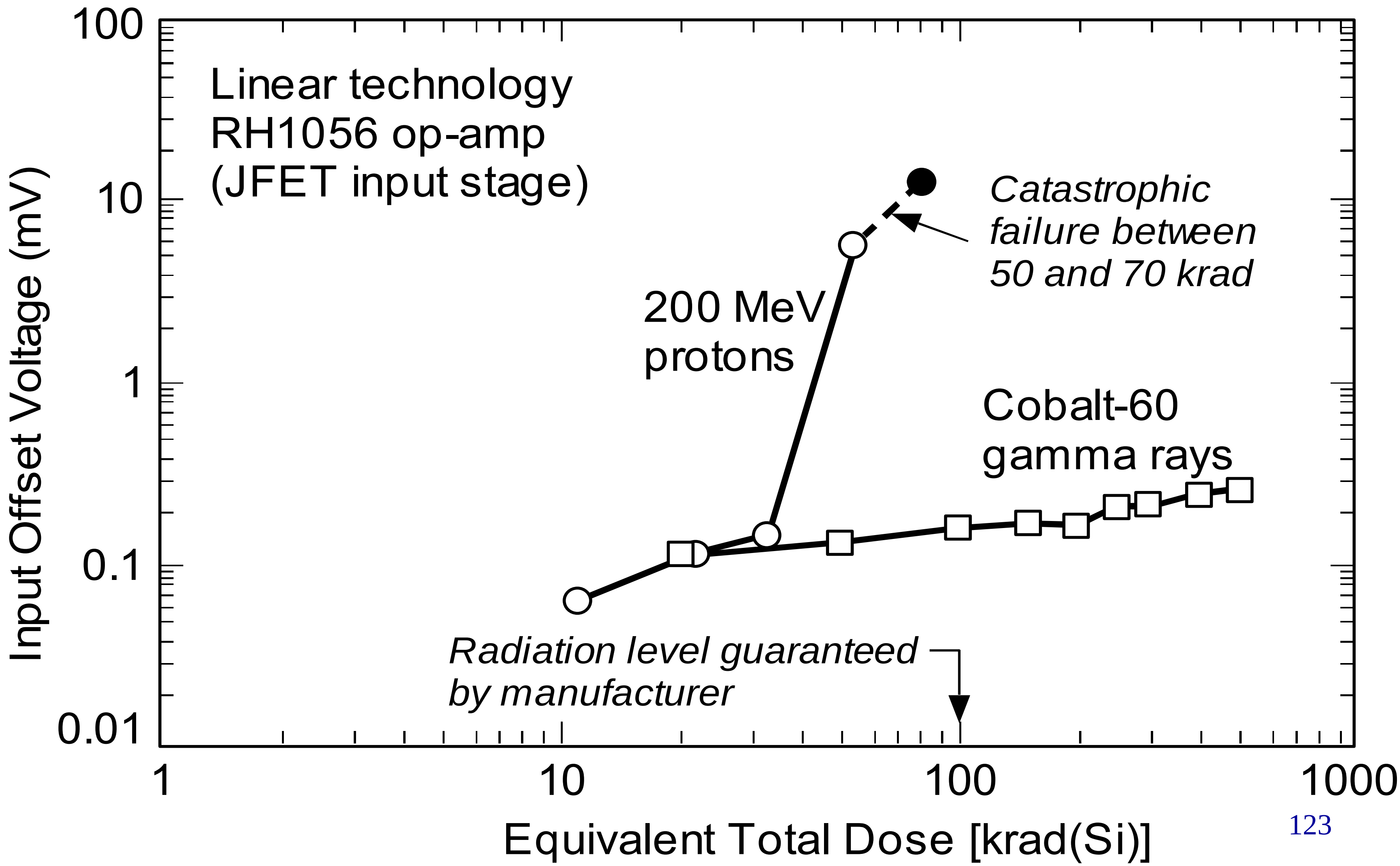
Effects of Gamma and Proton Irradiation on Input Bias Current of a Differential Comparator



Displacement Damage in a Voltage Regulator



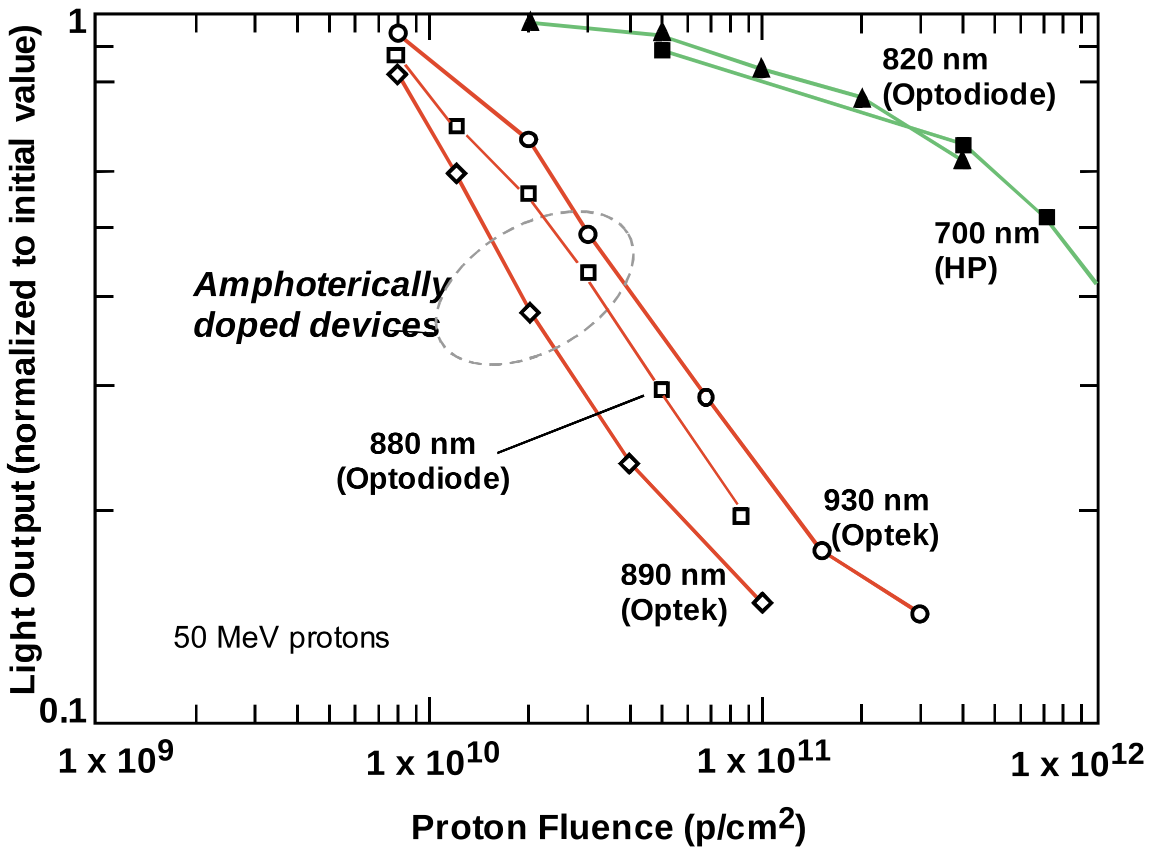
Displacement Damage in a Hardened Op-Amp



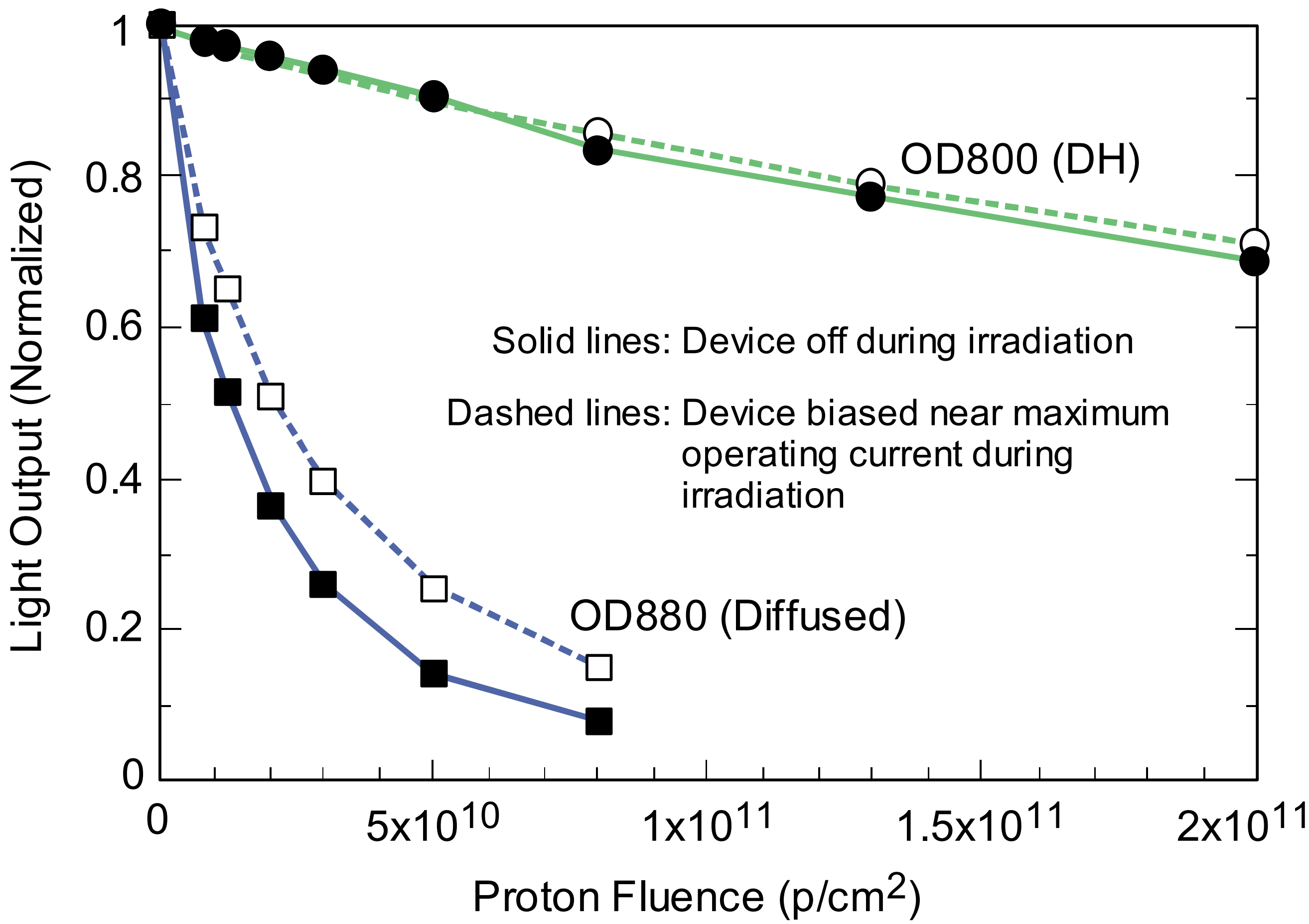
Displacement Damage Comparisons

Particle Type	Total Dose [rad(Si)]	Fluence ($\#/cm^2$)	Equiv. Neutron Fluence (n/cm^2)
electrons (100 MeV)	100k	3.3×10^{12}	3.8×10^{11}
electrons (2 MeV)	100k	4.1×10^{12}	8.6×10^{10}
protons (50 MeV)	100k	6.2×10^{11}	1.4×10^{12}

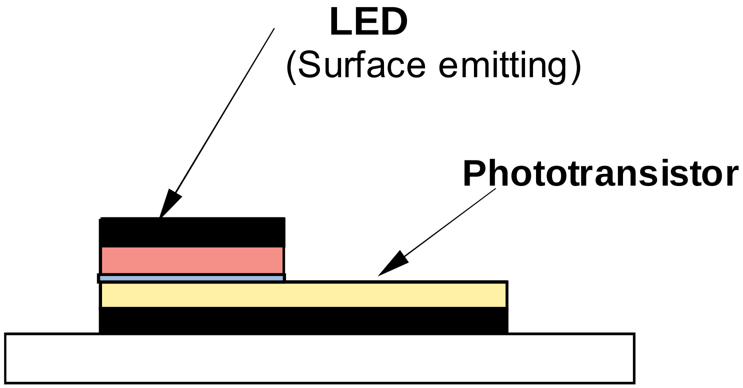
Degradation of Light-Emitting Diodes



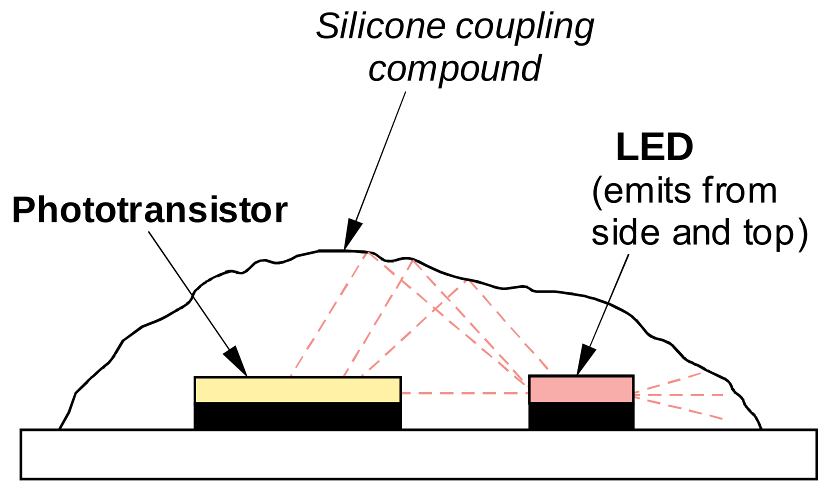
Comparison of Two LED Technologies



Optocoupler Construction

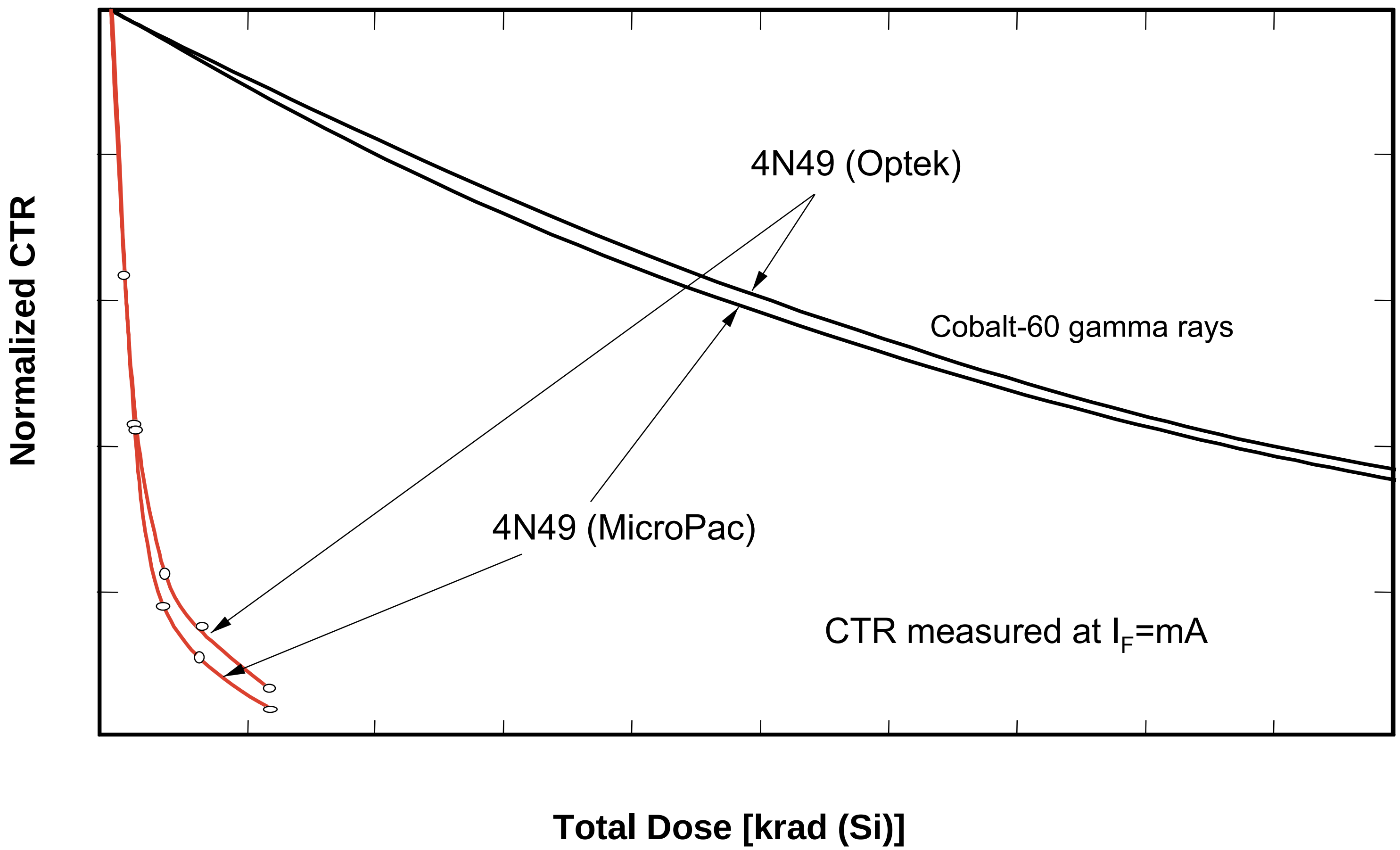


(a) Sandwich structure
(direct coupling to detector)



(b) Lateral structure
(reduced coupling efficiency)

Optocoupler Degradation



Failure of Optocouplers on Topex-Poseidon

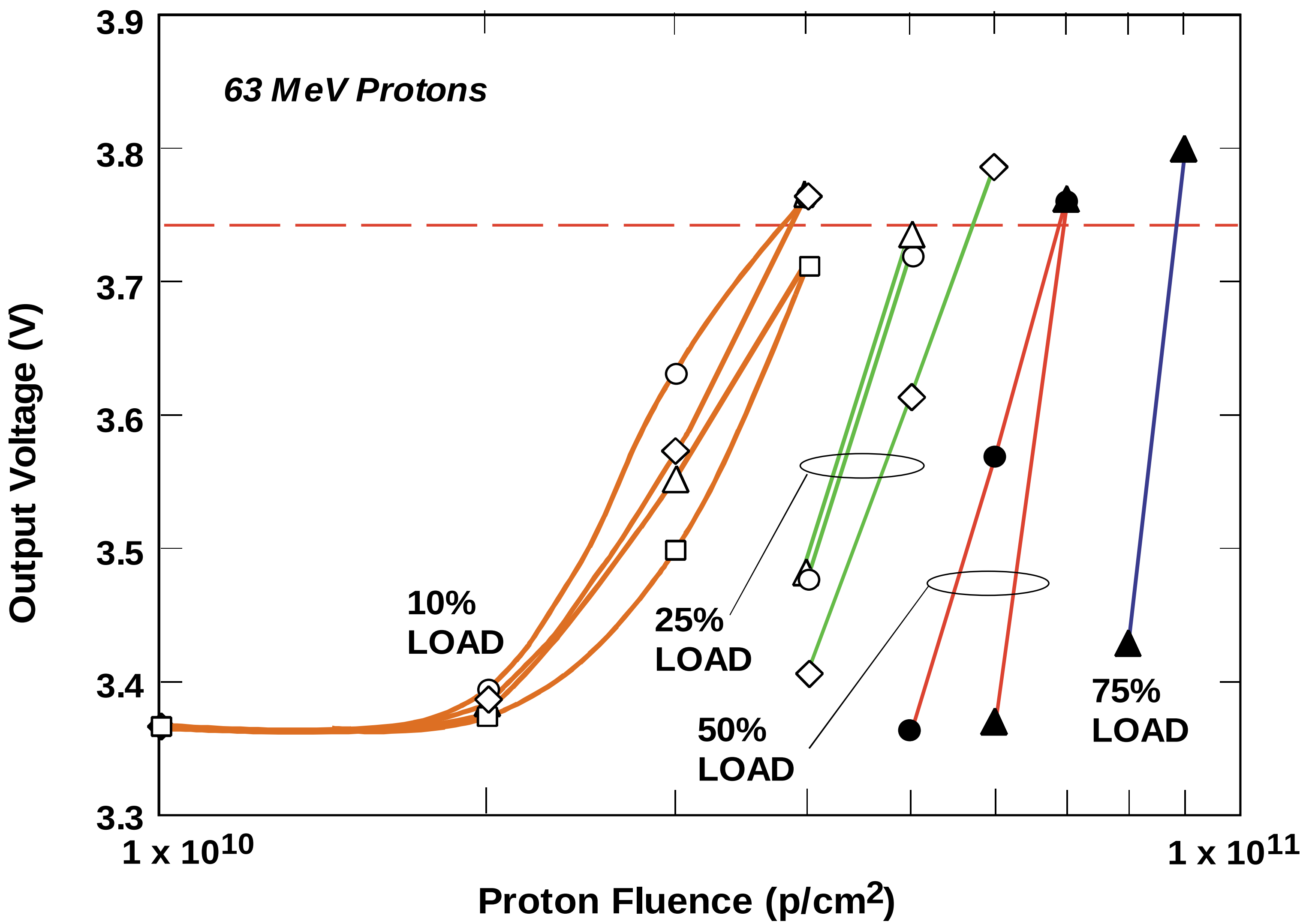
High-Inclination Earth Orbit

- 1300 km, 98 degrees
- Goes through lower edge of proton radiation belts

Optocouplers Used in Five Different Circuit Applications

- Failure occurred in thruster status application after 2.7 years
  - Design did not consider displacement damage
  - Circuit failure corresponds to a factor of four reduction in current-transfer ratio
  - Cold “spares” of little value for displacement damage
- Optocouplers continue to work satisfactorily in thruster firing circuit
  - Consequence of higher circuit margin used by designers

Failure of Power Converters Due to Optocoupler Degradation



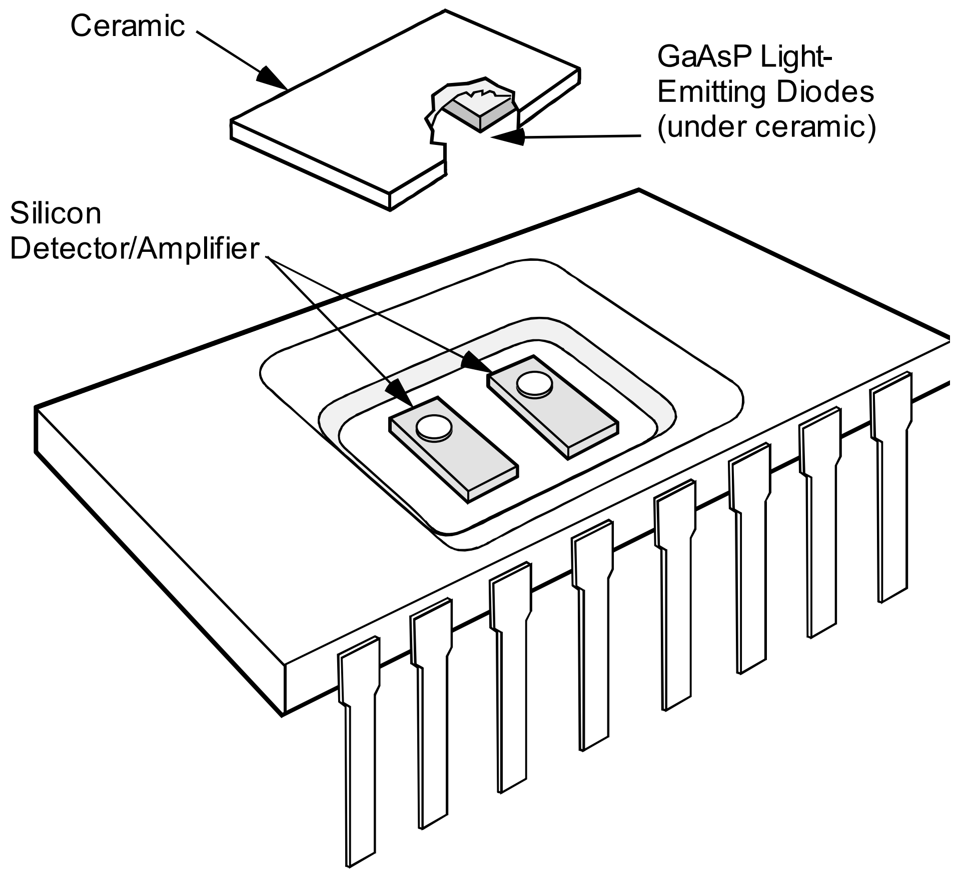
Optocoupler Transients

Voltage System Shutdown Occurred on Hubble Space Telescope

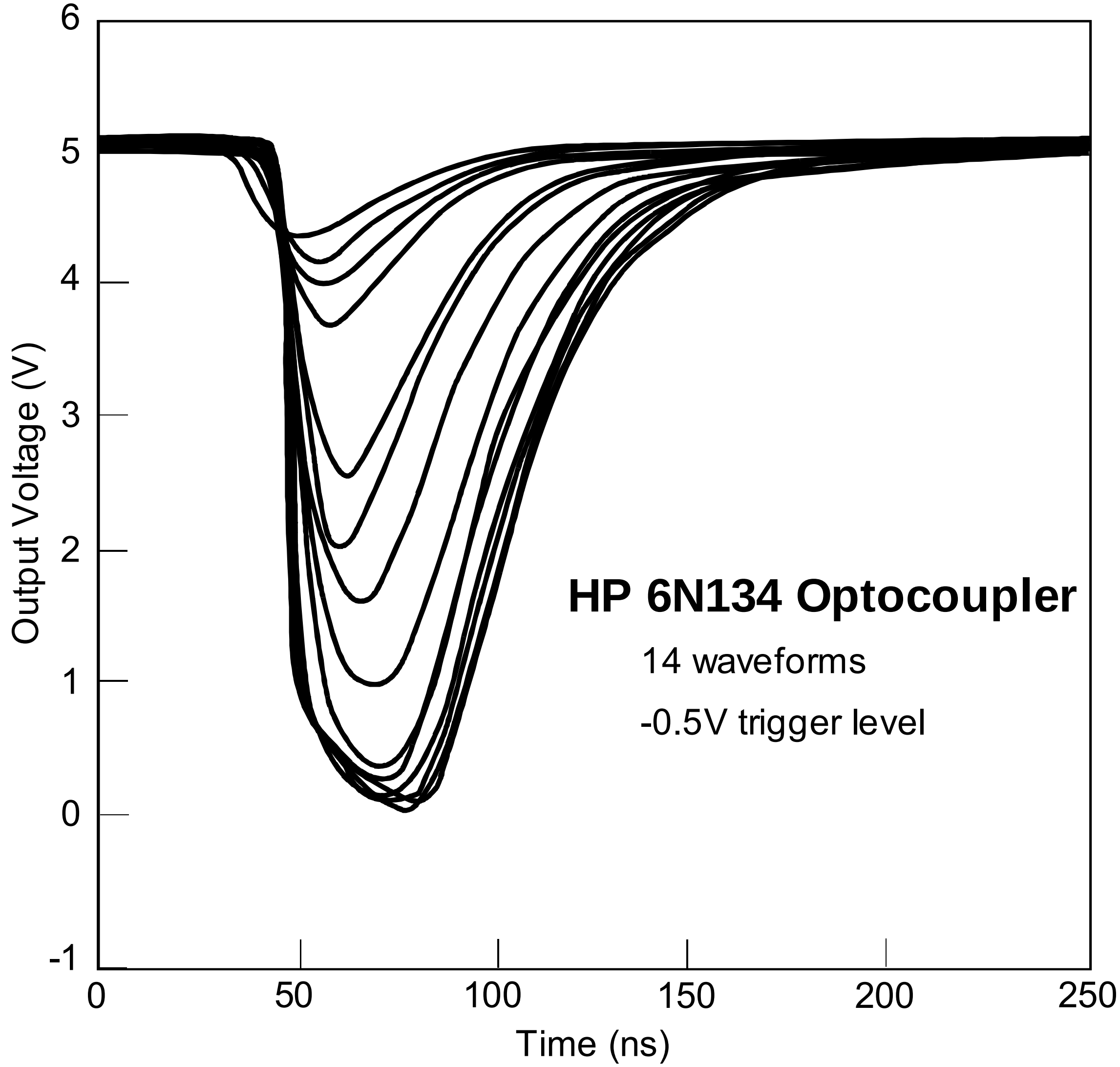
- Observed after upgraded electronics were installed
- Strongly correlated with orbit pattern

Laboratory Tests Showed that Shutdown Was Caused by Transients from Protons

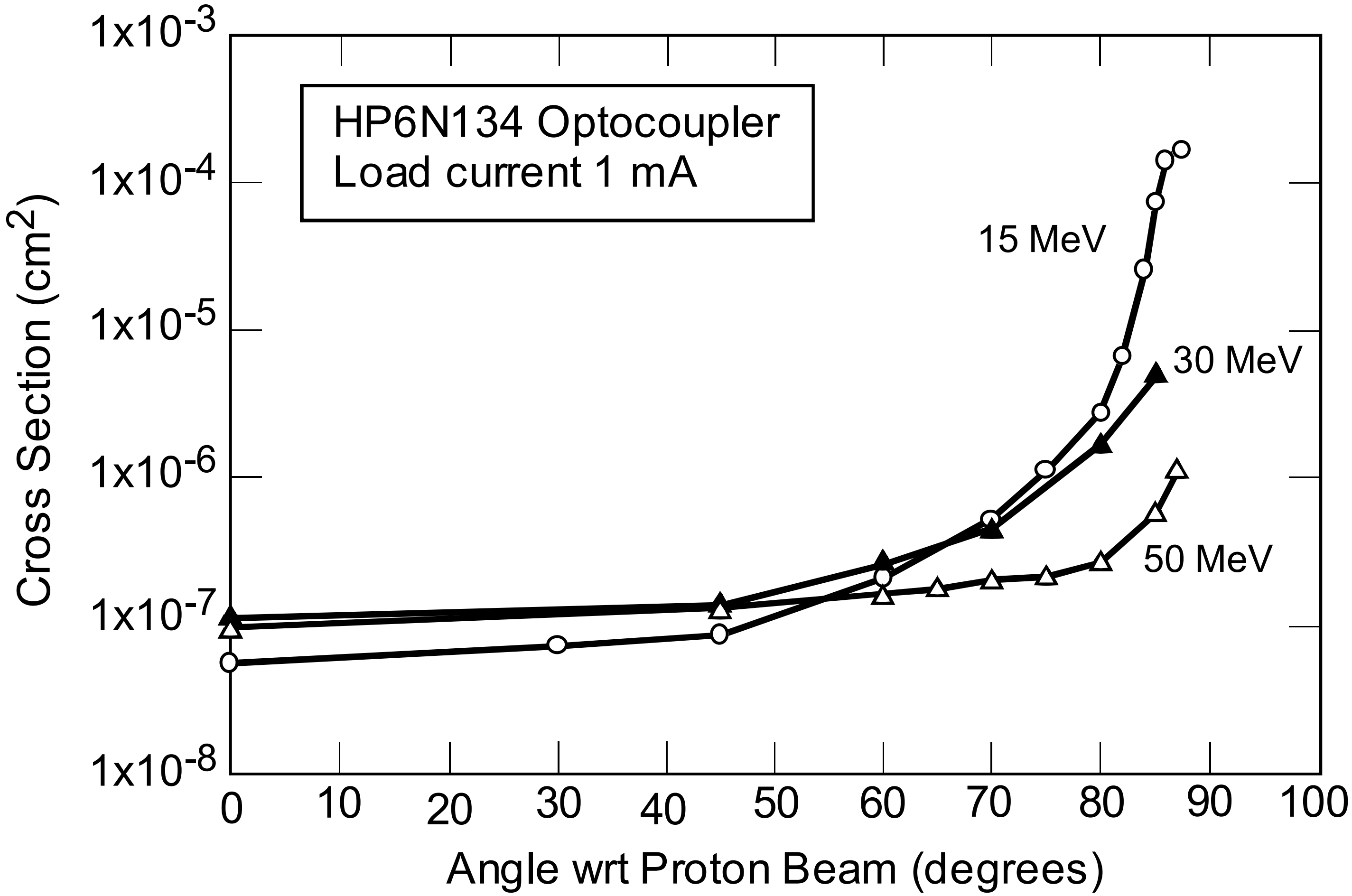
- Dominated by charge in photodetector
- Heavy ions also produce transients



Example of Transients from Protons for 6N134 Optocoupler



Angular Dependence of Proton Upset Cross Section



Course Summary

Environments and System Requirements

JPL Systems Have a Variety of Mission Requirements

- Short duration missions with low radiation levels
- Interplanetary missions with extremely high levels
- Earth-orbiting missions where proton effects dominate

Overall Mission Requirements Must Be Understood

- “Reflexive” policies and procedures should be avoided
- Testing is not always required

Using Parts Where Radiation Data Exists Can Be Cost Effective

Single-Event Upset

SEE Effects Have Become Worse As Parts Have Evolved

- Device scaling
- Complex internal design and architecture
- Functional interrupt problems

SEE Testing Has Become More Complex

- Device complexity
- New phenomena
- Multiple-bit upset

Successful Use of Commercial Parts Depends on System Design

Permanent Damage from Single-Particles

Latchup Is the Most Critical Catastrophic Damage Issue

- Many CMOS circuits are sensitive to latchup
- Difficult and costly to characterize latchup in detail
- Best alternative is to eliminate latchup-prone devices

Gate Rupture and Burnout Effects Are Becoming More Important

- Previously only an issue for power MOSFETs
- Permanent damage has been observed in pulse-width modulators
- Testing and qualification methods need to consider these effects

Total Dose Effects

Total Dose Damage Remains a Key Issue for Many Technologies

- **Field oxide failure causes huge increases and functional failure in CMOS**
- **Gate oxide threshold shift is important in many technologies**
- **Internal charge pumps are usually highly susceptible to total dose damage**

Low Dose Rate Damage Effects Are a Major Issue for Bipolar Devices

- **Problem not completely understood**
- **Wide variation among manufacturers**
- **JPL has an excellent facility for tests at very low dose rate**

Devices with High Maximum Voltage Ratings Are Often a Problem

- **Low doping levels**
- **Increased oxide thickness**

Permanent Damage from Protons and Electrons

Permanent Damage Issues Are Often Overlooked

Technologies Where Displacement Effects Matter

- Linear integrated circuits
- Light emitting diodes
- Optical detectors
- Optocouplers

Cobalt-60 Gamma Rays Are a Compromise

- Cost effective
- Appropriate for technologies where displacement damage doesn’t matter
- Provides no information about displacement damage effects